Lecture 17. Local and regional pollution issues: sources and dispersion of pollutants.

Objectives:
1. Distributed and point sources of the pollution.
2. Atmospheric stability.
3. Spatial and temporal scales of atmospheric processes.
4. Major transport processes:
   Diffusion. Turbulence. Convection. Advection and long-range transport.
5. Removal processes.

Readings: Turco: p.111-125; Brimblecombe: p. 130-138

1. Distributed and point sources of the pollution.

Sources of air pollutants can be distinguished by the characteristics of emissions- the type of materials, amount released per day (or per any time period), and spatial extent of the emitting region.

Point sources can be thought of as very localized in space.

Examples: smokestack; leaking gas pipeline; burning cigarette, etc.

Distributed sources cover a wide area, so pollution originates from the extended sources.

Examples: a collection of rice fields; the collective carbon dioxide emissions from the vehicles in a city; etc.

- The characterization of a source as either a point or a distributed source can depend on how one choose to aggregate the individual emissions that compose the source and on the spatial scales of the interest.

Examples: point source: a car for emission test;
distributed source: all cars in a city for evaluation of city air quality.

Statistics is used to evaluate the aggregated emission from the individual sources.

NOTE: Air pollution statistics will be discussed in Lecture 39.

- The size of pollutant source determines how the pollutant will be dispersed throughout the atmosphere because the movement of air takes place on many scales of size: from microscopic swirls (eddies) to waves as long as a continent.

NOTE: recall Lecture 4 on air motion

- Pollutants from any source (small or large, point or distributed) are dispersed, and can eventually be dispersed over the entire planet.

- The dispersion of pollutants that are easily removed from the atmosphere or are chemically unstable is limited by their residence time in the atmosphere.

Example: rain is a mechanism for keeping air clean because it removes soluble pollutants.

- The dispersion of secondary pollutants also depends on the time required for their production from primary emissions.

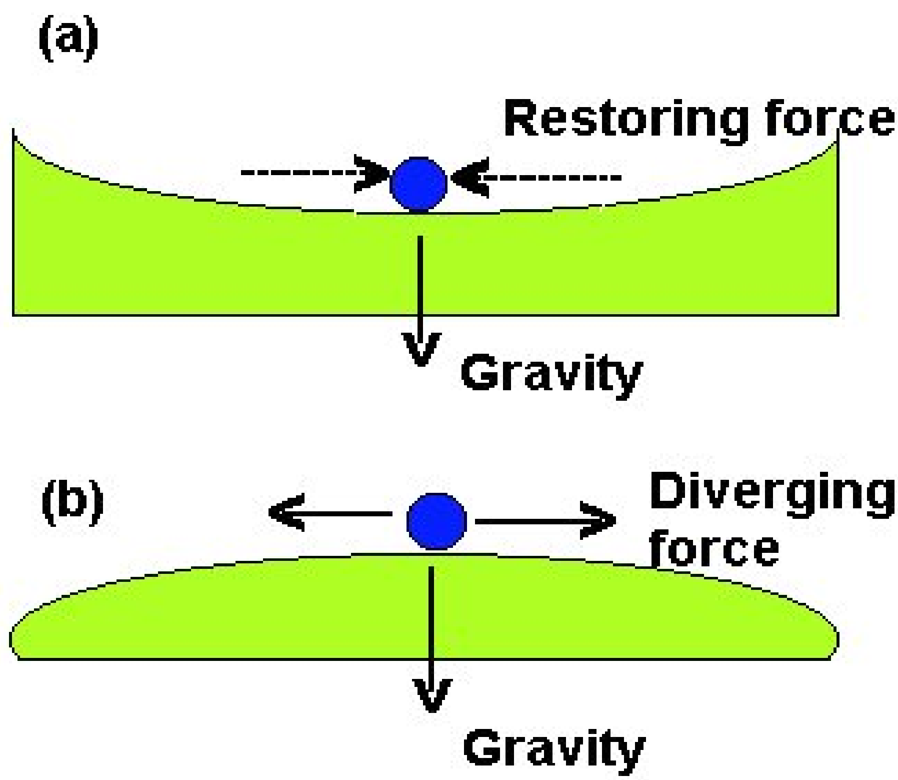
Example: ozone, a principal secondary pollutant in photochemical smog, can be generated in a matter of hours from primary pollutant, and, therefore, is both a local and a regional problem.

Tracer is any detectable species (anthropogenic or natural) in the atmosphere used to follow atmospheric processes or to study distribution of the species in the atmosphere. Air pollutant may be considered as a tracer in the atmosphere.

2. Atmospheric stability.

NOTE: recall Lecture 4: temperature structure in the lower troposphere, temperature lapse rates; dry adiabatic temperature lapse rate, potential temperature.

Figure 17.1 Illustration of a concept of stability: (a) stable condition; (b) unstable condition.



- Stability in the atmosphere is associated with the absence of vertical motion, and instability induces vertical motion.

Atmosphere is neutrally stable when parcels of local air that are displaced vertically simply remain where they are left. Neutral stability means that the buoyancy force is zero and that a balance exists between gravity (acting downward) and the pressure gradient force (acting upward).

Atmosphere is stable when a parcel of air, displaced vertically, up or down, returns to its original position (or buoyancy forces oppose vertical motion).

Atmosphere is unstable when a displaced parcel of air is continues moving in the direction of the displacement (or buoyancy forces enhance vertical motion).

- Atmosphere seldom has neutral stability, it is either unstable or stable.

Atmospheric stability occurs when warm air lies over cold air or when slightly cool air lies over warn air.

Example: at night, when the surface of earth cools.

Atmospheric unstability occurs when extremely cold air lies over warn air.

Example: 1) when the land surface, heated rapidly during the day, heats by conduction the layers of air just about the surface. If this air is warmer than air above it, the surface air rises by convection, and the cooler air above it sinks, causing instability.

2) when a layer of air, saturated with water vapor at the bottom and relatively dry at the top, is lifted in the atmosphere.

NOTE: on one sense the term atmospheric stability can imply the presence of a temperature inversion layer that inhibits vertical motions.

NOTE: large-scale temperature inversions are discussed in Lecture 18.

Environmental lapse rate, Γ_e, is defined as the negative of the actual change in temperature with altitude.

Atmospheric stability for dry (no liquid water present) air can be determined in one of two ways:

1. environmental lapse rate, Γ_e, can be compared to the dry adiabatic lapse rate, Γ_d, ($\Gamma_d = 9.76$ K/km; see Lecture 4).
2. potential temperature rate lapse can be compared to zero.

Mathematically, atmospheric stability can be determined as:

first way:

$\Gamma_e < \Gamma_d$ **for dry stable**

$\Gamma_e = \Gamma_d$ **for dry neutral**

$\Gamma_e > \Gamma_d$ **for dry unstable**

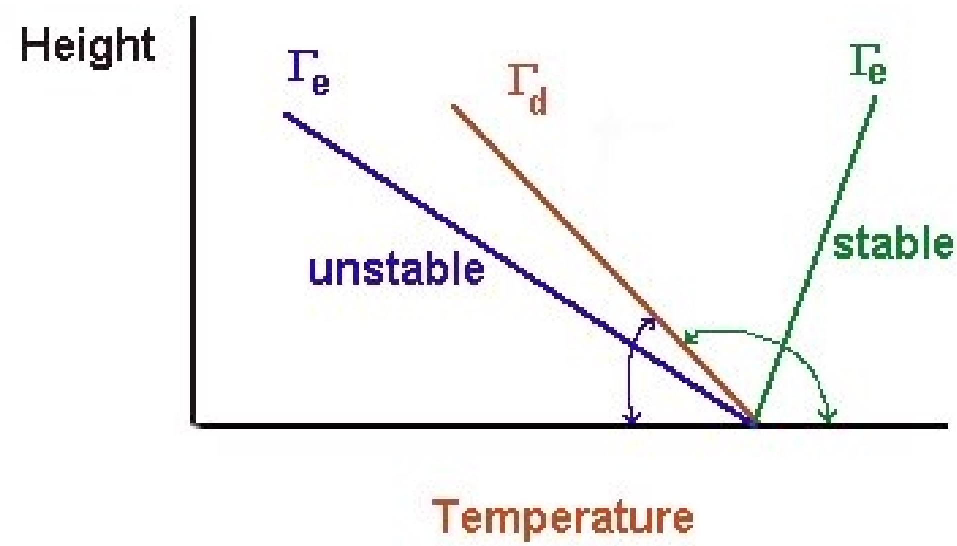
second way:

$d\Theta/dz > 0$ **for dry stable**

$d\Theta/dz = 0$ **for dry neutral**

$d\Theta/dz < 0$ **for dry unstable**

Figure 17.2 Demonstration of stability/instability in a dry atmosphere.



- Moisture can reduce the temperature lapse rate because when water vapor becomes saturated it condenses, releasing latent heat.

Saturated adiabatic lapse rate, Γ_s, is a change of the temperature of adiabatically rising air parcel, which is initially saturated at the ground.

- At any specific location and time, the temperature lapse rate normally has a value lying between the dry adiabatic lapse rate and the saturated adiabatic lapse rate, the two extremes.
- Because the atmosphere is highly variable, environmental lapse rate, Γ_e, is also variable. Moreover, the environmental lapse rate itself can change with altitude.

3. Spatial and temporal scales of atmospheric processes.

NOTE: recall local and regional winds, global air circulation defined in Lecture 4.

Air motion occurs in a range of spatial scales that vary from tiny eddies of a centimeter or less in size to huge air mass movements of continental dimensions.

The spatial scales of the various atmospheric chemical phenomena result from an intricate coupling between the chemical lifetimes of the principal species and the atmosphere's scales of motion.

Four rough categories to classify atmospheric scales of motion:

1. **Microscale.** Phenomena occurring on scales of order of 0 to 100 m, such as the meandering and dispersion of a chimney plume and the complicated flow regime in the wake of a large building.
2. **Mesoscale.** Phenomena occurring on scales of tens to hundreds of kilometers, such as land-sea breezes, mountain-valley winds, and migratory high- and low-pressure fronts.
3. **Synoptic scale.** Motions of whole weather systems, on scales of hundreds to thousands of kilometers.
4. **Global scale.** Phenomena occurring on scales exceeding 5 10^3 km.

- Each species in the atmosphere has a characteristic spatial transport scale.

Figure 17.3 Spatial and temporal scales of variability for atmospheric constituents.

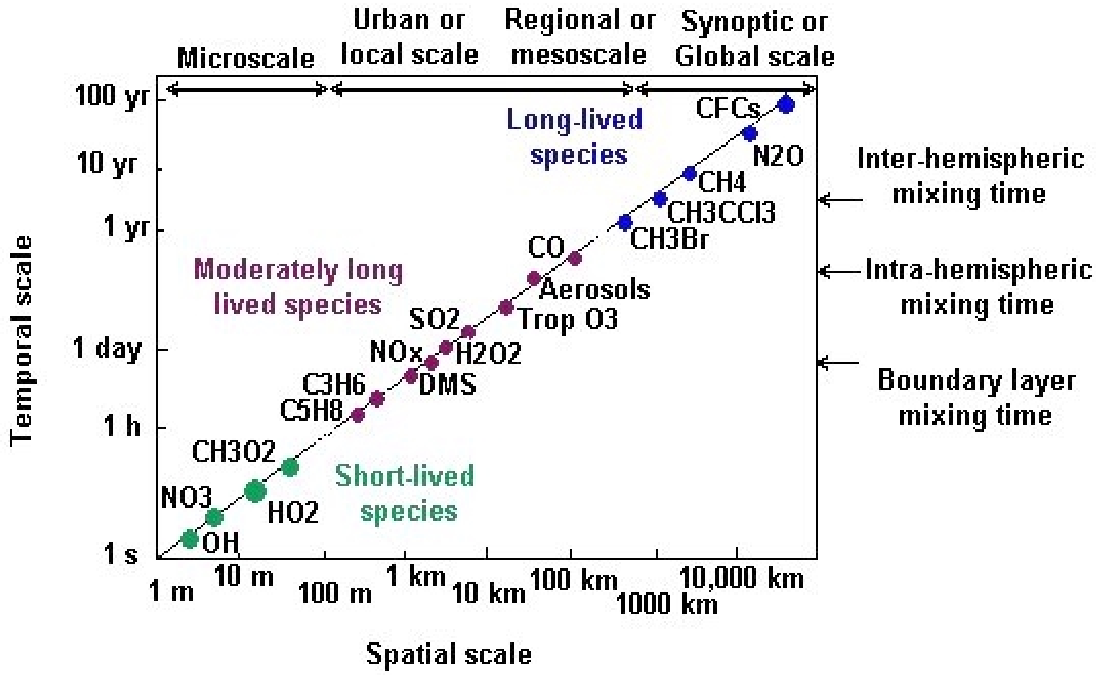


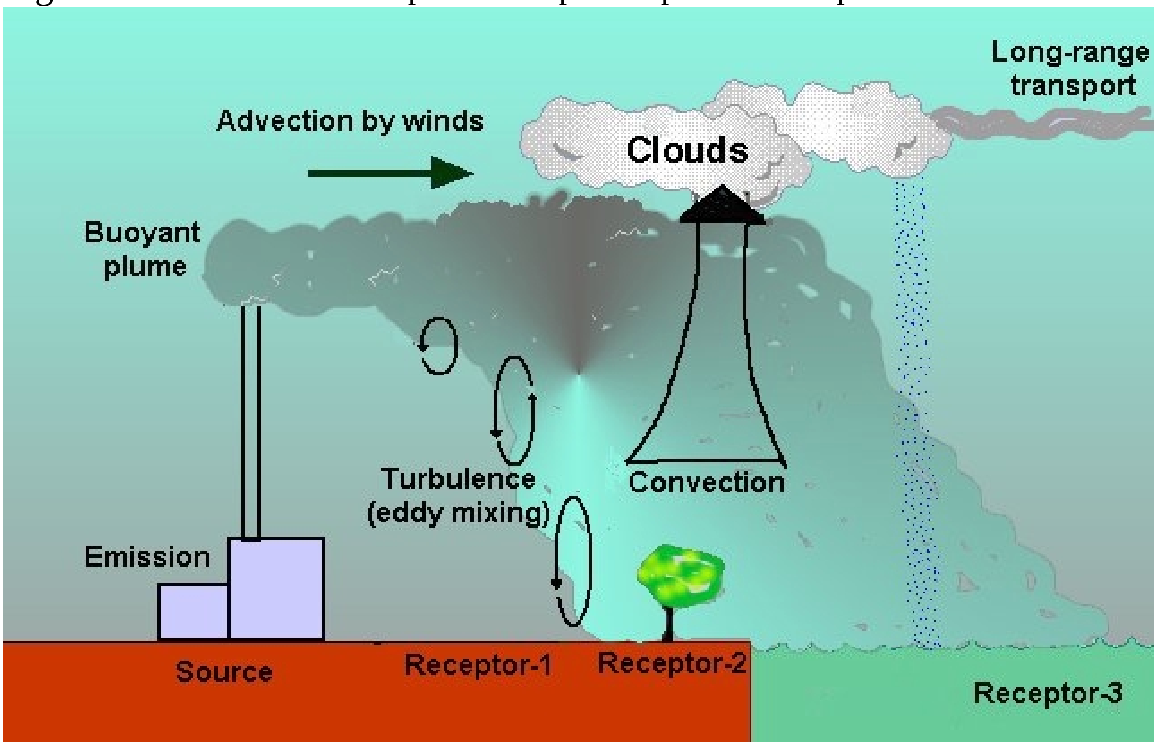
Table 17.1 Spatial scales of atmospheric chemical phenomena.

Phenomenon	Length scale (km)
Urban air pollution	1-100
Regional air pollution	10-1000
Acid rain/deposition	100-2000
Toxic air pollutants	0.1-100
Stratospheric ozone depletion	1000-40,000
Greenhouse gas increases	1000-40,000
Aerosol-climate interactions	100-40,000
Tropospheric transport and oxidation processes	1-40,000
Stratospheric-tropospheric exchange	0.1-100
Stratospheric transport and oxidation processes	1-40,000

4. Major transport processes: Diffusion. Turbulence. Convection. Advection.

- Pollutants are dispersed through a variety of processes involving the motions of air. These processes may be divided into the general categories of diffusion, turbulence, convection, and advection.

Figure 17.4 The various transport and dispersion processes for pollutants.



Diffusion and Turbulence.

Diffusion (molecular diffusion) is the average motion of a molecule (or particle) as a result of its collisions with other molecules (or particles).

- The average distance that each molecule moves is constrained by the frequency of its collisions with other molecules.

- Diffusion is not a very effective mechanism of air molecule transport because of high frequency of air molecule collisions. For instance, at STP the frequency of air molecule collisions is about 1 billion collisions per second.

- A pollutant tracer will be diffused from one point to another if the pollutant is not uniformly mixed in the atmosphere. In other words, in the case of molecular diffusion, the transport of a tracer occurs as a result of gradients in its concentration from place to place.

Turbulence (or turbulent diffusion) is the irregular air movement in which the wind constantly varies in speed and direction. This complex motion can be usually decomposed into individual vortices, or eddies. In the air that is agitated, all sizes all eddies can exist. The combination of all eddies acting simultaneously produces the effect called turbulence.

- Turbulence can be generated by any process that induces motion in a fluid like the atmosphere.
- Atmospheric turbulence near the Earth's surface differs from that at higher levels. When solar radiation heats up the surface, which in turn warms the air, the warm, light air rises, and cooler, denser air descends to replace it (recall buoyancy law discussed in Lecture 4). That movement of air, together with disturbances around surface obstacles, makes low-level winds extremely irregular.
- At altitudes of several thousand meters or more, the frictional effect of surface topography on the wind is greatly reduced, and the small-scale turbulence that is characteristic of the lower atmosphere is absent. Although upper-level winds usually are relatively regular, they sometimes become turbulent enough to have an effect on aviation.

Importance of turbulence:

Turbulence is important because it churns and mixes the atmosphere and causes water vapor, air pollutants, and other substances, as well as energy, to become distributed at all elevations.

Convection.

Convection is vertical motion driven by buoyancy.

- Convection is a localized phenomenon, driven primarily by surface heating during the day.
- The convective eddies and the smaller eddies comprising turbulence work together to create a mixed layer of air at the ground during the day.

Height (or depth) of the mixed layer depends on the amount of heating at the surface and on the temperature stability. The more heating there is, and the less stability there is, the higher layer will be.

Mixed layer tends to be shallow at night, in cold weather, and over the oceans because the buoyancy generated at the surface, which drives convection, turbulence, and mixing is relatively weak.

Importance of convective transport of air pollutants:

1. Convection lofts pollutants away from the surface. Where they otherwise could be in contact with people, plans, and animals.
2. In the rising convective column, precipitation may form and wash out the soluble pollutants.
3. Convection transports some pollutants into upper air levels with stronger prevailing winds; these winds are strong enough to disperse the pollutants over great distances.

Advection and long-range transport.

Advection is a horizontal motion of the atmosphere, and the prevailing winds are known as advective winds.

NOTE: recall Lecture 4 on principal wind systems.

- The fastest winds are find aloft, in the jet streams.

Example: velocities of advective winds aloft may be up to 400 km/h;

velocities of winds near the surface are about 10 to 20 km/h

Importance of advective transport of pollutants:

1. **Advection removes the pollutants to a distance from the source.**
2. **Advection acts to dilute the pollutants.**
3. **Advection is the process responsible for the long-range transport of pollutants downwind from sources.**

5. Removal processes.

- Pollutants leave the atmosphere by gravitational settling (or sedimentation, dry deposition, and wet deposition. These processes are also called removal processes.

Gravitational settling (or sedimentation): is the sinking of particles in the atmosphere due to downward force of gravity. Sedimentation removes most particles whose diameter are greater than about 1 μm. Particles less than 1 μm in diameter are often small enough to stay in the atmosphere for long periods. Particles greater than 10 μm in diameter quickly settle out. Gases also sediment; however, their weights are so small that their sedimentation velocities are essentially negligible.

Dry deposition is a process that causes both gases and particles to be removed from the atmosphere at the air-surface layer. Dry deposition occurs when gases or particles impact and stick to a surface near or on the ground. For instance, gases or particles can deposit onto trees, buildings, grass, the ocean surface, car windows, or any other surface.

Wet deposition is a process by which cloud or rain drops scavenge gases and particles while falling to the surface. The ability of the rain to remove pollutants depends upon the rainfall intensity, the size and electrical properties of the drops, and the solubility of the polluting species.

Problem

What is the lifetime of ozone by dry deposition in a 300 m deep atmospheric boundary layer? Assume that ozone has a dry deposition velocity of 0.5 cm/s.

Solution:

The lifetime of a species by dry deposition is

$\tau = H / v$

Thus, the lifetime of ozone is

$\tau = 300\ 100\ \text{cm} / 0.1\ \text{cm s}^{-1} = 3\ 10^{5}\ \text{s}$